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Principal Investigator: Gregory P. Asner

Final Report: Regional Impacts of Woodland Expansion on Nitrogen Oxide Emissions from Texas Savannas: Combining Field, Modeling & Remote Sensing Approaches. Award# NGT5-30348

In support of the doctorate work of Roberta E. Martin at the University of Colorado.

Woody encroachment has contributed to documented changes world-wide and locally in the southwestern U.S. Specifically, in North Texas rangelands encroaching mesquite (*Prosopis glandulosa* var. *glandulosa*) a known N-fixing species has caused changes in aboveground biomass. While measurements of aboveground plant production are relatively common, measures of soil N availability are scarce and vary widely. N trace gas emissions (nitric and nitrous oxide) from soils reflect patterns in current N cycling rates and availability as they are stimulated by inputs of organic and inorganic N. Quantification of N oxide emissions from savanna soils may depend upon the spatial distribution of woody plant canopies, and specifically upon the changes in N availability and cycling and subsequent N trace gas production as influenced by the shift from herbaceous to woody vegetation type. The main goal of this research was to determine whether remotely sensible parameters of vegetation structure and soil type could be used to quantify biogeochemical changes in N at local, landscape and regional scales.

To accomplish this goal, field-based measurements of N trace gases were carried out between 2000-2001, encompassing the acquisition of imaging spectrometer data from the NASA Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) on September 29, 2001. Both biotic (vegetation type and soil organic N) and abiotic (soil type, soil pH, temperature, soil moisture, and soil inorganic N) controls were analyzed for their contributions to observed spatial and temporal variation in soil N gas fluxes. These plot level studies were used to develop relationships between spatially extensive, field-based measurements of N oxide fluxes and remotely sensible aboveground vegetation and soil properties, and to evaluate the short-term controls over N oxide emissions through intensive field wetting experiments. The relationship between N oxide emissions, remotely-sensed parameters (vegetation cover, and soil type), and physical controls (soil moisture, and temperature) permitted the regional scale quantification of soil N oxides emissions. Landscape scale analysis linking N oxide emissions with cover change revealed an alleviation from N limitation following mesquite invasion.

This study demonstrated the advantage of using N trace gases as a measure of ecosystem N availability combined with remote sensing to characterize the spatial heterogeneity in ecosystem parameters at a scale commensurate with field-based measurements of these properties. Woody vegetation encroachment provided an opportunity to capitalize on detection of the remotely-sensible parameter of woody cover as it relates to belowground biogeochemical processes that determine N trace gas production. The first spatially-explicit estimates of NO flux were calculated based on *Prosopis* fractional cover derived from high resolution remote sensing estimates of fractional woody cover (< 4 m) for a 120 km² region of North Texas. An assessment of both N stocks and fluxes from the study revealed an alleviation of N limitation at this site experiencing recent woody encroachment.

Many arid and semi-arid regions of the world are experiencing woody invasions, often of N-fixing species. The issue of woody encroachment is in the center of an ecological and political debate. Improving the links between biogeochemical processes and remote sensing of ecosystem properties will improve our understanding of biogeochemical processes at the regional scale, thus providing a means to address issues of land-use and land-cover change.

Peer-reviewed papers produced from this thesis

- Martin, R.E., G.P. Asner, R.J. Ansley, A.R. Mosier. In press 2003. Effects of Woody Vegetation Encroachment on Soil Nitrogen Oxide Emissions in a Temperate Savanna, *Ecological Applications*.
- Martin, R.E., G.P. Asner. In review. Regional Nitrogen Oxide Emissions Following Woody Encroachment: Linking Imaging Spectroscopy and Field Studies. *Ecosystems*.
- Martin, R.E., G.P. Asner. Submitted. Woody encroachment alters nitrogen cycle in rangelands. *Geophysical Research Letters*.

Thesis Abstract (approved April 4, 2003)

Martin, Roberta Enders (Ph.D., Geological Sciences, University of Colorado)

Effects of Woody Encroachment on Savanna Nitrogen Dynamics: Combining Biogeochemistry and Remote Sensing

Thesis directed by Assistant Professor Gregory P. Asner

Woody encroachment, the increase of woody plant density relative to herbaceous vegetation, has contributed to documented biophysical and biogeochemical changes world-wide, and locally in the southwestern U.S. In North Texas rangelands, encroaching mesquite (*Prosopis glandulosa* var. *glandulosa*), a known nitrogen (N)-fixing species, has caused changes in aboveground biomass. However, the impacts of woody encroachment on N cycling have not been well studied, despite the central role that N dynamics play in controlling carbon (C) cycling and many other ecological processes across all spatial scales from microbial soil processes to global plant productivity. Airborne remote sensing is arguably the only approach available to develop a spatially-explicit understanding of ecosystem processes. The main goal of this research was to determine whether remotely sensible parameters of vegetation structure could be used to quantify biogeochemical changes in N at the local, landscape and regional scale.

To accomplish this goal, I first characterized the impact of woody encroachment on soil nitrogen oxide (nitric-NO and nitrous-N₂O oxide) emissions. I examined biotic (vegetation type and soil organic and inorganic N dynamics) and abiotic (soil moisture, temperature, and soil texture) controls over soil NO and N₂O emissions across a gradient of aboveground (AG) *Prosopis* biomass growing on two soil types. Soil N oxide fluxes were dominated by NO emissions produced during nitrification. I found that AG biomass was the best spatial predictor of NO emissions. Emissions also co-varied with soil pH and clay content. Microsite position - under or away from mesquite canopies - did not influence NO emission rates at the site level. NO fluxes were four times higher from clay loam than shallow clay soils; however, soil N properties (total organic N and extractable inorganic N) and cycling rates (mineralization and nitrification) did not differ significantly across the sites. Temporally, NO emissions and nitrification potential were positively correlated with temperature, and precipitation events elevated NO emissions 4-fold over a 24 h period and producing small amounts of N₂O. I concluded that mesquite encroachment in these grasslands

increased NO emissions in a spatially explicit manner influenced by the AG biomass and soil type, which was then temporally mediated by temperature and secondarily by precipitation.

Based on these results, I combined hyperspectral remote sensing and field measurements to quantify spatial patterns and to estimate regional fluxes of soil NO emissions across 120 km² of semi-arid rangeland in North Texas. This analysis captured the high spatial variability of NO emissions as they co-varied with vegetation cover and soil type across the region. A remotely-derived annual NO emission estimate that included temperature and precipitation was 160 kg NO-N km⁻² y⁻¹, almost twice that of the value derived from traditional averaging of field measurements. I concluded that relationships between NO emissions and remotely sensed structure and composition are advantageous for quantifying NO emissions at the regional scale. Linking emissions rates to remotely-sensible vegetation parameters also provided a means to quantify the role of land use (e.g. brush management) on biogeochemical processes which, are highly variable and otherwise difficult to measure at the regional scale.

Finally, an assessment of the ecosystem N status following woody encroachment was conducted. I determined the magnitude of changes in N stocks and fluxes following woody expansion across a North Texas rangeland. I then used a combination of N stock and flux observations to assess overall changes in ecosystem N inputs relative to plant N requirements. N increased in aboveground vegetation (woody and grass) and litter in all cases, but changes in soil N stocks were not pronounced. These patterns differed by soil texture. Plant N requirements remained in balance with N inputs on higher clay content soils, which sustain low amounts of biomass, even as plant production increased. In contrast, N inputs exceeded N requirements in both vegetation types on finer textured soils indicating, widespread alleviation of N limitation. Differences in N associated with woody and herbaceous canopies - often used to assess the magnitude of changes attributed to woody encroachment - were readily distinguishable in the systems of low overall N status. These relative differences lessened as gross N quantity increased.

Nitrogen is considered to be the most limiting nutrient to plant production in terrestrial ecosystems world-wide. The concept that increased N inputs via biological N fixation by woody plants such as *Prosopis* could alter the long-term balance of N in an ecosystem relative to that required for plant production is not new. However, measurement of N inputs relative to plant N requirement is difficult, and in the context of recent woody expansion into grasslands, may not capture short-term changes in N

dynamics that impact the long-term trajectories of ecosystem development. The results presented in this thesis provide an understanding of the impacts of woody encroachment on N dynamics, which potentially affect the long-term structure and function of arid and semi-arid ecosystems.